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FORCE-REFLECTING INTERFACES TO TELEMANIPULATORS TESTING SYSTEM (FITTS) INTERIM USER'S GUIDE

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BIODYNAMICS AND BIOENGINEERING DIVISION

December 1990

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This User's Guide specifies the procedures for operating the Force-reflecting Interfaces to Telemanipulators Testing System (FITTS) at the Harry G. Armstrong Aerospace Medical Research Laboratory. The report first describes each FITTS subsystem: the American Cimflex Merlin 6500 robots, the MB Associates exoskeleton, the AF/Navy Teleoperator Performance Evaluation Battery, and the control computers. After providing step-by-step procedures for initializing each subsystem, this User's Guide describes how to operate FITTS either by telemanipulation or by computer control. Next the report presents the process used to analyze experimental data collected with FITTS. Finally a section is provided which describes error recovery steps to be used with FITTS.

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Contents

1 Preface

Associate yourself with men of good quality if you esteem your own reputation - G Washington

This *Interim Users' Guide* is written for those who need to know how to operate the Force-reflecting Interfaces to Telemanipulators Testing System (FITTS). Examples might be to give a telemanipulation demonstration, to run a force feedback experiment, or to investigate some parameter of a FITTS subsystem. This guide isn't intended to be a robotics manual - the reader need not be a robotics expert to learn how to operate the system. Neither does this text contain instructions for replacing FITTS code with new control or communication algorithms. That important topic is discussed in the technical literature which describes the various FITTS subsystems.

The reader is assumed to have a working knowledge of MS-DOS (tm), along with a general knowledge of the FITTS hardware. To prevent inadvertent damage to the equipment, any deficiencies in these areas should be corrected before attempting to run FITTS. Consult the appropriate reference listed in Section 9, *For Additional Information . . .*, if you need to study a particular subsystem.

This *Users' Guide* is in an interim stage primarily because the Merlin robots do not yet have a force sensing capability. FITTS therefore has no method of providing force feedback from the slave robots to the human interface. This situation is temporary; however, this *Users' Guide* was completed before a force sensing capability was installed, in the interest of program continuity during personnel changes.

The authors thank those who have worked so diligently to make FITTS possible: Captain Ron Julian, then-Captain Mark Jaster, and Captain Terrell Scoggins for their foresight and program management skills; Captain Ammon Wright, Dr. Dan Repperger, Ron Dallman, Gary Merrill, Todd Mosher, and John Babel for their technical wizardry; Jeff Logan for making it all work; and especially Monty Crabill for continuing this challenging mission despite frequent, sometimes radical, program changes.

2 Introduction to FITTS

A carelessly planned project takes three times longer to complete than expected; if carefully planned, it will take only twice as long - Golub

The Force-reflecting Interfaces to Telemanipulators Testing System, known as FITTS, was developed at the Harry G. Armstrong Aerospace Medical Research Laboratory (AAMRL) to study current operator interfaces to telemanipulation systems. By developing a better understanding of the limitations of today's operator interfaces, it is hoped we will spawn the next generation of interfaces with more intuitive control of the remote robots. This section will briefly describe the goals of the FITTS system, and introduce each FITTS subsystem.

FITTS is based on the premise that the best teleoperator system performance will occur when the operator receives as much feedback from the worksite as is needed to perform the tasks without being overburdened with too much information. FITTS is designed to study this feedback requirement, specifically, the operator's requirements for force feedback from the worksite. By using FITTS to develop new operator interfaces with the proper type and amount of force feedback, we should realize more "natural" control over the slave robots. This improved control is one step towards moving teleoperation out of semi-structured environments (such as the nuclear fuels reprocessing "hot cells") and into completely unstructured hazardous work sites with dynamic environments.

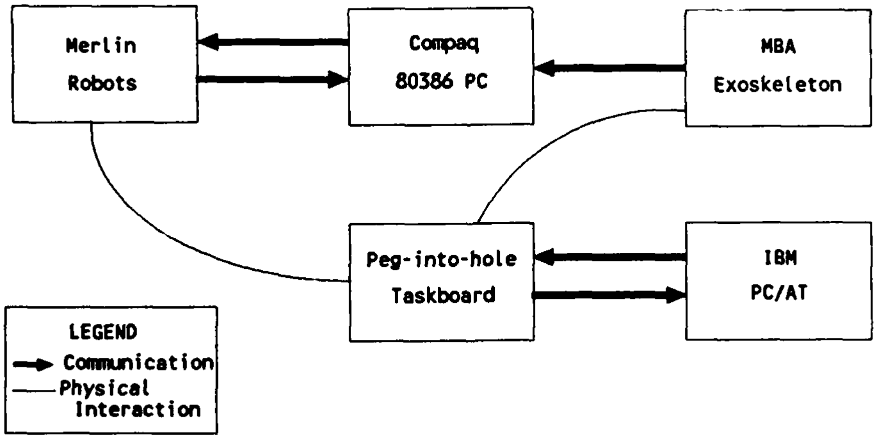


Figure 1. FITTS subsystems and their interactions.

FITTS is composed of several subsystems, working together as shown in Figure 1. Primary among these subsystems are the Merlin robots, MBA exoskeleton, peg-into-hole taskboard, and control computers. These subsystems work together to form an integrated testbed for evaluating the performance of various telemanipulation operator interfaces. Each of these subsystems is briefly described below.

2.1 Slave Robot Subsystem

The Merlin robots are key components of this testing system (see Figure 2). These robots can be controlled in any of the following three ways:

1. Using the robot's teach pendant (the joystick attached to the Merlin Control Cabinet). With this joystick you may individually control each joint of the robot, or you may move the gripper along one of the [x, y, z, roll, pitch, yaw] axes.
2. Running the file *computer* on the Compaq, and interactively assigning to each joint a specific position or velocity of motion.
3. Wearing the MBA Exoskeleton and commanding the robot's gripper to mimic your hand motions. Even though this control scheme causes the Merlin gripper to follow your hand motions, the Merlin's joint angles will not be identical to your arm's joint angles. This occurs because the human arm contains a redundant degree of freedom, absent from the 6 degree-of-freedom Merlins.

Figure 2. American Cimflex Merlin industrial robots.

All of the three control methods outlined above result in position or velocity commands being transmitted to the Merlin robots. The operator of FITTS is responsible to ensure these commands do not cause the robot to move into any obstacles. Because force feedback is not being transmitted to the operator, the robots may attempt to continue moving through an obstacle (such as the floor), causing very large forces to build up at the robot/environment interface. Either the environment or the robot could be damaged by allowing this to happen.

By using these large industrial robots as slaves in FITTS, we have made our testbed "operator paced." That is, the slave robots can move at least as fast as the human operator. This ensures that the performance of our system depends on the limitations of the operator interfaces, not the dynamic limits of the slave robots. At the time this *Users' Guide* was written, only the left-arm Merlin robot was prepared for this high speed operation.

2.2 Operator Interface Subsystem

The MBA exoskeleton is the first operator interface to be evaluated by FITTS. As you can see in Figure 3, this exoskeleton is mechanically passive; that is, its joints are not actuated by motors. Therefore the forces acting on the slave robot are not reflected back to the operator. Because of this passivity we expect the performance of the MBA exoskeleton, when controlling the FITTS slave robots, to be much less than the optimal performance of a human. The performance of this exoskeleton is important nonetheless: it is one of the baselines against which we will compare newer operator interfaces, such as force-reflecting exoskeletons or joysticks. We expect future operator interfaces to show marked improvement over today's state-of-the-art.

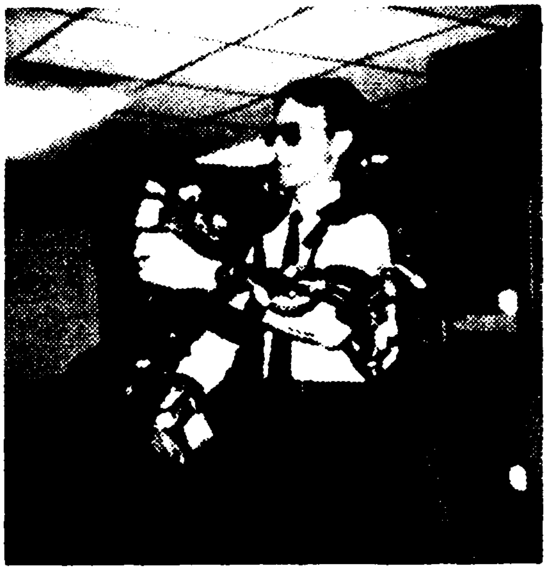


Figure 3. MBA exoskeleton.

When worn, this exoskeleton is tightly coupled to the motions of the human arm. Each joint of the exoskeleton contains an optical encoder which digitally determines the angle of that joint. The backpack of the MBA Exoskeleton contains a Motorola 68000 microprocessor, which reads each optical encoder value and transmits this information serially to the Compaq computer. The Compaq computer then calculates the operator's hand position and sends this position to the Merlin robots.

2.3 Task Subsystem

The peg-into-hole taskboard shown in Figure 4 is the basic research tool used in FITTS to study the performance of teleoperated systems. This taskboard was designed and built by the Naval Oceans Systems Center, Hawaii, and AAMRL, to provide a consistent method of performance measurement. It will be used to develop standard metrics of telemanipulator task performance. We are currently using the time to complete standard tasks as this performance measure (cf. Fitts [1954]). Because the taskboard may be used hands-on, or via teleoperation, we can compare various operator interfaces (joysticks, exoskeletons, etc.) to our testbed, plus we can compare telerobotic performance of tasks with a human performing the same tasks hands-on. Since the ability of an operator to perform these tasks is degraded by many factors (e.g., by increasing the difficulty of the task, by using a poorly designed interface, or by distracting the operator with extraneous information), the standard peg-into-hole tasks are valuable for quantifying these many dimensions of the telerobotic control problem into one performance metric.

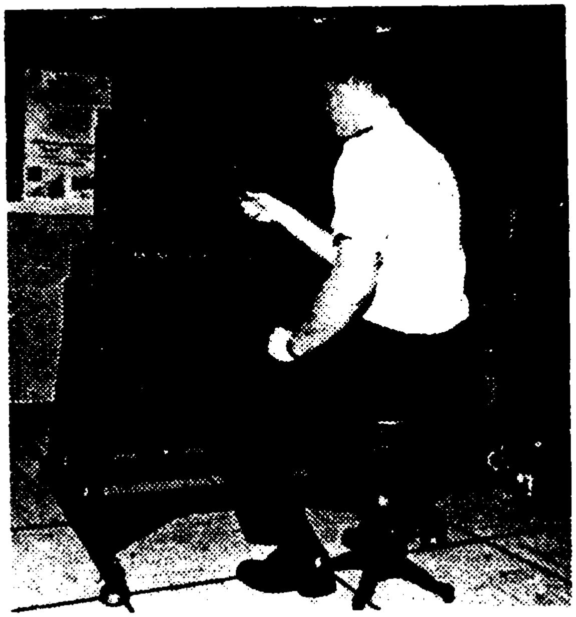


Figure 4. Subject performing peg-into-hole tasks.

2.4 Computation Subsystems

The MBA exoskeleton and the Merlin robots are controlled by a central control computer (Compaq 33 MHz 80386). The peg-into-hole taskboard is controlled by a separate control computer (IBM 12 MHz 80286). Programs written for these computers allow you to operate the robots under interactive computer control or as slaves for teleoperation. The *Users' Guide* does not describe how to enhance these programs - that is left for the various technical manuals. This *Users' Guide* will describe how to run the various programs on the computers, as you use FITTS to study the human's interface to teleoperated systems.

The next section lists those procedures you must follow every time you use particular FITTS subsystems. The two sections following that will describe details specific to operating FITTS under either computer control or teleoperation. Be sure you follow all safety precautions (preceded by the word **WARNING** or **CAUTION**) when working with these systems.

3 Starting the System

A trip of many miles begins with a single step - Confucius

Since the FITTS subsystems can be integrated in several configurations, the procedures you must follow to start FITTS depend on your objectives (see Figure 5). For example, if you will be studying a human's ability to perform peg-into-hole tasks without being encumbered by an exoskeleton, you won't need to turn on the Merlin robots or the MBA exoskeleton. On the other hand, giving a telemanipulation demonstration won't often require that you use the taskboard. Because of the "it depends" nature of using FITTS, this section is divided into three parts: initializing the slave robots, using the taskboard, and initializing the MBA exoskeleton.

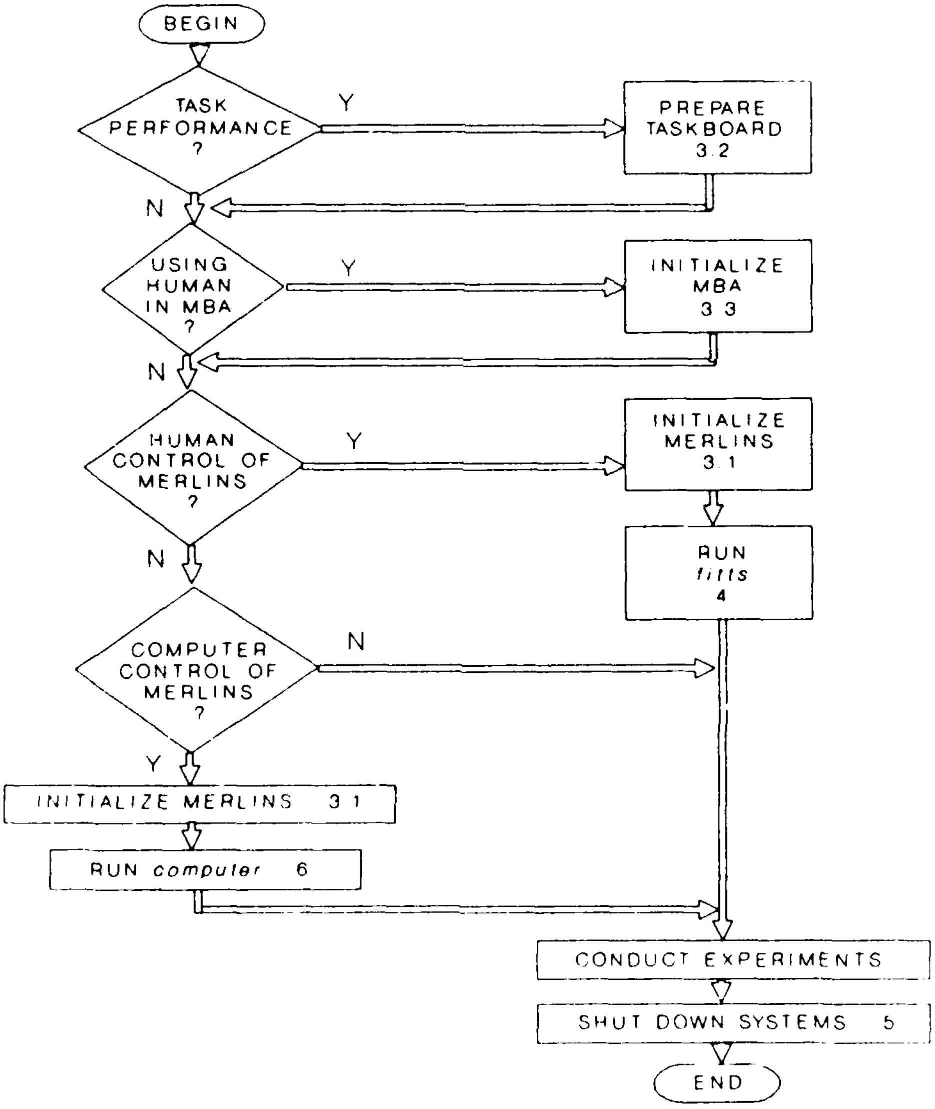


Figure 5. Flow chart for operating FITTS.

3.1 Initializing the Slave Robots

Each time you operate the FITTS slave robots, you must first calibrate their joint positions and initialize the computer-robot communications channel. Be forewarned: preparing each Merlin robot for teleoperation takes 10 minutes on a good day, and could take longer if you aren't used to positioning the joints using the joystick. Since only the left-arm Merlin is currently operating under high speed control, this section will only address preparing that robot for use. When the right-arm robot is ready for high speed operation, the procedures will be similar to the following procedures for the left-arm robot:

- initializing the peripherals (3.1.1)
- loading the system software (3.1.2)
- moving each joint to its calibration position (3.1.3)
- calibrating the joints (3.1.4)
- loading the high speed software (3.1.5)

Each of these procedures is given below.

3.1.1 Initializing the Peripherals

CAUTION

It is important to turn on the light fence and disable the motors with the intrusion detection circuit before turning on power to the robots. Otherwise, the robots might move unexpectedly when power is applied, damaging either the robot or the environment.

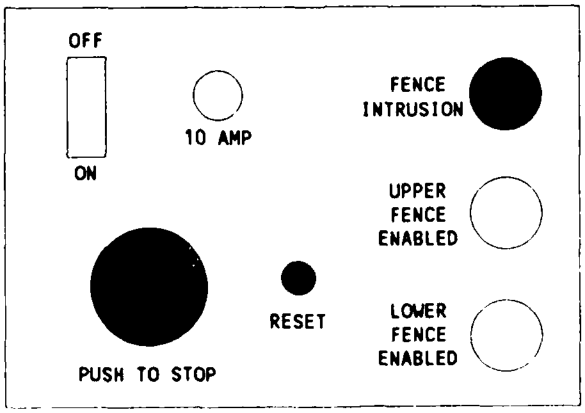


Figure 6. Light fence control panel.

You must power up the Merlin console video display terminal (VDT) and the light fence before using the Merlin robots. Power is provided to the work bench by turning on the extension cord's power strip. The power switch for the Merlin console VDT is on the left side of the VDT. The switch for the light fence is on the light fence control panel (see Figure 6). Make sure that both the upper and lower sections of the light fence are enabled (both green li-hts are lit). If either section is not enabled, refer to Section 8, *Error Recovery*. Press the ***Push to Stop*** button on the light fence control panel to make sure the intrusion detection circuit has been triggered (the red *fence intrusion* light should be lit). Do not press the light fence *reset* button yet.

3.1.2 Loading the System Software

First, make sure you have the following three Merlin disks available:

- Magix System (tm) Disk
- AR-BASIC (tm) Disk
- High Speed Host Interface (HSHI) Disk

Then, follow these steps to boot the robots (performed at the Merlin's control cabinet):

- Place the Magix System disk in the Merlin control cabinet's top disk drive, and the AR-BASIC disk in the bottom drive.
- Double check the light fence to be sure the red *fence intrusion* light is lit.
- Turn the keyswitch on the Merlin control cabinet to the *reset* position.
- Flip up the *master power* switch at the bottom front of the Merlin control cabinet chassis.
- Press the *power on* buttonswitch. Several console lights will flash.
- Turn the keyswitch to the *prog* position.

You must now wait (about six minutes) while the system software loads. You will know the robot is ready when the AR-BASIC system appears on the Merlin console VDT, and the VDT's cursor is waiting for input with the > prompt located in the middle of the screen.

3.1.3 Moving Each Joint to its Calibration Position

You are now ready to calibrate the robot. To do this first check that the six calibration points located on the Merlin robot, listed in Table 1, are aligned. You may want to use the universal protractor to make sure both the upper and lower arm segments are parallel to the floor.

Table 1 - Merlin Calibration Markers

Joint	Position
Waist	Orange marker on waist aligns with white line on base
Shoulder	White line on upper arm aligns with white V on shoulder
Elbow	Forearm parallel to floor
Wrist Roll	Orange wrist marker aligns with top center of forearm
Wrist Pitch	Wrist level - not pitched up or down
Hand Roll	Orange gripper marker aligns with slot on mounting plate

To begin calibrating the robot, type *calibrate pwr* at the Merlin console VDT (a shortcut is to hold down the *cmd* key and press c). The system should respond with the following message at the bottom of the VDT: *Position robot arm, then press F1 (or F3 to abort).* **DO NOT PRESS F1 AT THIS TIME.** Instead you must decide if each of the calibration positions are aligned. If so, skip to Section 3.1.4, *Calibrating the Joints.* If the joints are not aligned, you must use the Merlin teach pendant to move each joint into position. The teach pendant is located on the face of the Merlin control cabinet. Remove the pendant from the cabinet. You will notice that it is quite cumbersome and will take some getting used to.

Follow these steps:

- Make sure the teach pendant *motors off* light is on. This light is located near the center of the teach pendant. If the light is off, press the black *motors off* button on the teach pendant.
- Ensure the *emergency stop* rocker switch, located just below the *motors off* light on the teach pendant, is in the *run* position.
- Reset the light fence. You should hear the motors engage.
- Check the leftmost rocker switch on the face of the teach pendant. If this switch is set to *position*, your commands will control the three large motors of the robot (waist, shoulder, and elbow). If the switch is in the *orientation* setting, your commands will move the wrist motors. Set the switch to the setting you desire.

WARNING

Do not move the robot until all people are out of the workspace.

CAUTION

It is not always intuitive to understand in what motion your joystick commands will result. Be careful not to move the robot into any obstructions, such as the floor or the robot's pedestal. This is especially important when the robot is holding an object in its gripper.

- Move the proper axis by holding in the black button on the upper left side of the teach pendant, and moving the joystick.
- Move the robot joints so that all six calibration markers are properly aligned (refer to Table 1).
- Return the teach pendant to the front of the Merlin control cabinet.

3.1.4 Calibrating the Joints

To continue with the robot's calibration, check that the *motors off* light (located on the face of the teach pendant) is lit. Press the black *motors off* button on the face of the teach pendant if the light is off. Then check the light fence control panel. If the red *fence intrusion* light is lit, press the *reset* button (you should hear the motors running). Now press the *F1* key. You will see the robot move each joint, then return to the calibration position. When you see the > prompt again, you know the robot has been calibrated. If the robot does not return to the calibration position, the initial alignment was off. Return to Section 3.1.3, *Moving Each Joint to its Calibration Position*, being careful to properly align each calibration marker.

3.1.5 Loading the High Speed Software

Your final step in initializing the slave robots is to load the high speed software. You do this by shutting down the robots and re-booting them with the high speed software, as follows:

- Disable the light fence by pressing the *Push to Stop* button on the light fence control panel, or by passing your hand through one of the light beams (you should hear the motors turn off).
- Exit AR-BASIC by typing *bye* at the > prompt (on the Merlin console).
- When you see the menu of choices, select *F4 - Shut System Down.* Respond to the question that follows by tapping the *F1* key. The operating system will inform you when the shutdown is complete.

CAUTION

Do not turn off the main power to the robot chassis, or all of the calibration information will be lost.

- Turn on the Compaq Personal Computer (two switches must be used, on the front panel of the chassis and the front of the monitor).
- Remove both disks from the Merlin control cabinet disk drives, and place the HSHI disk into the top drive.

- Turn the keyswitch on the Merlin control cabinet to the *reset* position, and back to the *prog* position. You must now wait about three minutes until the HSHI system is loaded.
- Once you see the HSHI menu of choices, type the *F1* key to select *HSHI Host.* In about two minutes the robots will be ready for operation.

3.2 Using the Taskboard

Fortunately the taskboard is not as complicated to initialize as are the Merlin robots. In fact, you can prepare the taskboard for operation while you are waiting for the Merlin software to load.

The taskboard is controlled through the rainbow-colored ribbon cable extending out the back of the IBM PC-AT. Make sure this cable is inserted into the taskboard interface connector with the brown wire aligning with connection #1. The rest of this procedure is done through the PC.

Once the PC is booted, type *nosc*. You will see a short batch file execute. You will also be prompted to enter the current day, month, and year. After you enter this data the computer will tell you the Julian date. Remember this number; you will need to use it later. When the DOS prompt re-appears, you have several choices of which taskboard control programs you want to run:

- Run the *switches* program to test all 16 switches.
- Run *tbc_l* to collect data using the large taskboard holes.
- Run *tbc_s* to collect data using the small taskboard holes.

When running the *tbc_l* or *tbc_s* experimentation files, you must answer several questions about the experiment before the program is ready for data collection. The following section describes what your answers to these questions mean with respect to the experiment's data files.

Trial order file name. You have several files of peg-into-hole tasks available to be run. For a complete description of these files, see the *Peg-in-Hole Taskboard Documentation.* Basically, you may choose to run a subject on one of three practice files (prac24n.1, prac24n.3, or prac24n.5, where n = s for the small taskboard holes and n = l for the large holes) or one of six experimentation files (trial_n.x, where n = s for the small taskboard holes and n = l for the large holes; x = [1..6]). Each practice file contains 24 peg transfer tasks, while the experimentation files contain 36 tasks.

Operator ID. The task data collected during the experiments is saved in two uniquely-named DOS files. The first three letters of these filenames are the three initials of the subject (not the experiment proctor). The inside front cover of the taskboard logbook contains the three-letter initials of all subjects tested so far. If another subject duplicates one of these sets of initials, assign a pseudo-set of initials to this subject, using the concatenation of the subject's first initial, last initial, and a sequence number (e.g., SR2 instead of SJR). Annotate all new initials in the front of this logbook.

Session code. This is a one-digit code to uniquely identify a subject's separate experiment trials for a given day. Start each day's experiments with the number 0, incrementing each experiment by

1. If you have selected a practice file, start the session codes with the letter P, and increment each subsequent practice trial by one letter.

Julian date. The three-digit Julian date (e.g., 044 for February 13th) is appended to the subject's initials in the data file names.

Year. The last digit of the year is appended to the Julian date in these filenames.

Because the experimentation data files and data file headers are critical for the analysis of data for an experiment, read the *Peg-in-Hole Taskboard Documentation* to determine the proper input for each of the header items that appear on the next screen. Be particularly careful to ensure that item #3, *Controller type (hardware oriented)*, is correct - use an N for hands-on and an X if the subject is wearing the MBA Exoskeleton. If all of the data items are correct, type an *x* to continue with the experiment.

When a subject is being timed on the taskboard, s/he must first insert the peg into the starting hole, maintaining appropriate insertion pressure to keep the microswitch at the bottom of the hole closed. After three seconds of constant switch closure, the green LED will light on the taskboard interface connector. The proctor should then tell the subject to proceed to the target hole. If a switch bounces, or the subject moves to the wrong target hole, or the peg slips in the subject's hand, the subject may elect to return the peg to the start hole without ever inserting the peg into the target hole. If this happens, the subject must wait another three seconds before the green LED lights again.

We currently use MYSTAT (tm) to analyze the data collected during an experiment. Refer to the Section 7, *Analyzing Taskboard Data,* for a description of the method currently being used to evaluate this data.

3.3 Initializing the MBA Exoskeleton

Preparing the MBA Exoskeleton is relatively straightforward. Once all sixteen optical encoders of the exoskeleton (fourteen joints plus two grippers) are passed through their home, or zero, positions, the device is ready for telemanipulation. Use the following three steps to initialize the MBA exoskeleton:

- Ensure the continuous-roll joints of the exoskeleton's upper and lower arm segments are approximately at their zero positions (so the elbow segment runs along the outside of the human arm). When these joints are properly aligned the exoskeleton structure "lines up," that is, the transitions from the upper arm link to the elbow and from the elbow to the lower arm link appear to be continuous.
- Turn on the power switch to the backpack. You should see most, if not all, of the LEDs on the gripper panels turn on.
- Rotate each joint of both arms through its range of motion to pass it through the zero position. As each joint passes through its zero position, the LED corresponding to that joint will turn

off. The meaning of each LED is given in Table 2. Close both grippers to turn off their LEDs.

Table 2 - Exoskeleton LED Symbols

LED	Meaning
GP	gripper (open/close)
WF	wrist flexure (hand pitch)
WR	wrist roll (hand yaw)
LR	lower arm roll (hand roll)
EB	elbow
UA	upper arm roll
SE	shoulder elevation (vertical motion)
SA	shoulder azimuth (horizontal motion)

All 16 LEDs should now be reset. If any remain lit, consult Section 8, *Error Recovery.*

4 Telemanipulation

The human brain is a wonderful thing. It starts working the moment you are born and doesn't stop until you stand up to speak in public - G Jessel

This section lists those procedures you must follow to operate the left-arm Merlin robot under exoskeletal control. When the right-arm Merlin is ready for high speed operation, the required procedures will just be an extension of these.

To prepare FITTS for telemanipulation, follow these steps:

- Clear the Merlin's workspace of all unwanted obstacles
- Initialize the robot as described in Section 3.1
- Initialize the exoskeleton as described in Section 3.3
- Prepare the taskboard as described in Section 3.2 (if desired)

WARNING

The Merlin robot does not have force limiting. This means that you could damage the robot or the environment if you try moving the robot through a stiff obstacle.

The following steps will cause the left-arm robot to begin mimicking the gripper of the exoskeleton's left arm. During the next step, the Compaq computer will prompt you to reset the light fence. Before doing so, *make sure someone is wearing the MBA Exoskeleton, and the operator's left arm is nearly straight out.* This safeguard will prepare you to hit one of the panic buttons (such as the light fence *Push to Stop* button) if you see the robot moving to a position other than straight out.

CAUTION

Before proceeding, find the nearest *Emergency Stop* button. Be ready to use the *Emergency Stop* feature if the robot makes any unexpected motions.

- Run the batch file *fitts* on the Compaq. Enter a 1 at the first question from the Compaq. The program will delay for approximately 7 seconds, then the computer will sound a beep. As soon as the next key is pressed, the robots will be operating under exoskeletal control.
- Stop the telemanipulation by passing your hand through the light fence, or by pressing one of the *Emergency Stop* buttons. Depending on the status of the communications port when the machines were stopped, you may need to re-boot the Compaq computer and re-run the batch file *fitts* once again to repeat telemanipulation.

WARNING

Do not reset the light fence without restarting *fitts* on the Compaq, or the robot will attempt to move to an unpredictable position.

When possible you should return the Merlin to its calibration position when you are finished with the telemanipulation. By returning the robot to its calibration position, you make calibrating the robot much easier the next time. The proper way to reset the Merlin is given in the next section, *Shutting Down the System.*

5 Shutting Down the System

Something attempted, something done,
Has earned a night's repose: - Longfellow

For the most part, terminating a FITTS session is straightforward - you finish the experiment and shut off the equipment. This procedure works for the taskboard (turn off the IBM PC/AT) and for the MBA Exoskeleton (turn the switch on the exoskeleton backpack to off). There is one exception to this procedure, which occurs when you shut down the Merlin robots.

You should use the following procedures to shut down the Merlin robots after either a telemanipulation or a computer-control experiment.

WARNING

Complete the following steps in the order listed to ensure the robots do not move unexpectedly during the shutdown process.

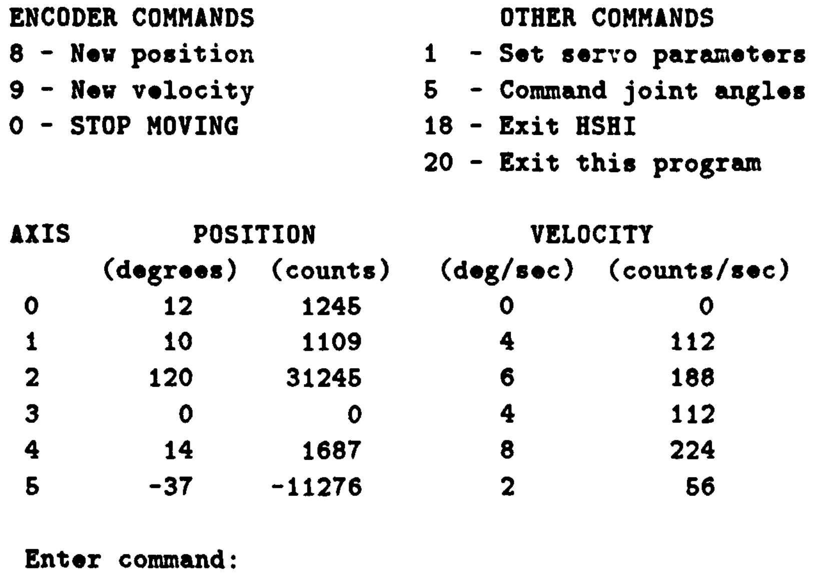
1. First ensure the red *fence intrusion* light on the light fence control panel is lit. If this light is off, press the *Push to Stop* button on the light fence control panel.
2. Run the batch file *computer* on the Compaq.
3. Select command *1 - Set servo parameters* on the Compaq. When prompted, enter a value of 1 for each parameter (maximum acceleration, maximum velocity, loop gain).
4. Press the red *reset* button on the light fence control panel. You should hear the Merlin motors engage.
5. Select command *8 - New position* on the Compaq. Enter a value of 0 for each of the robot's six joints. You will see the robot move (slowly) back to the original calibration position as each of the joints is set to zero.
6. Press the *Push to Stop* button on the light fence control panel after the robot returns to the calibration position.
7. Select command *18 - Exit HSHI* on the Compaq. You will see a display on the Merlin console VDT indicating the HSHI program is terminated.
8. Select *F7 - System Shutdown* on the Merlin console VDT. You will see an inquiry on the Merlin console VDT asking whether or not you want to shut down the system.
9. Tap the *F1* key in response to the Merlin system's prompt.

Now that the Merlin has been returned to the calibration position, and the HSHI program was properly exited, you can turn off power to the Merlin console VDT and the light fence. Turn the keyswitch on the Merlin chassis to *reset*, and remove the *HSHI* disk. Then power down the Merlin control cabinet (the switch is at the bottom front of the Merlin chassis). You should also turn off the Compaq computer (the switches for both the monitor and the CPU are on the front panels). You are now finished with the shut-down process.

6 Computer Control of FITTS

At the source of every error which is blamed on the computer you will find at least two human errors, including the error of blaming it on the computer - Glib

If you are investigating the workspace of the Merlin robots, or you want to study the dynamics of the robots, you probably want to operate them with discrete computer commands (independent of the MBA exoskeleton). In this case, first calibrate the robots following the steps of Section 3.1, *Initializing the Slave Robots.* Next, turn on the Compaq computer (and its monitor) and run the batch file *computer.* You will see a screen similar to Figure 7.



```
ENCODER COMMANDS                OTHER COMMANDS
8 - New position           1  - Set servo parameters
9 - New velocity           5  - Command joint angles
0 - STOP MOVING            18 - Exit HSHI
                           20 - Exit this program

AXIS        POSITION              VELOCITY
      (degrees)  (counts)   (deg/sec)  (counts/sec)
 0       12        1245         0           0
 1       10        1109         4         112
 2      120       31245         6         188
 3        0           0         4         112
 4       14        1687         8         224
 5      -37      -11276         2          56

 Enter command:
```

Figure 7. Menu for computer control of the Merlin robots.

Since the *High Speed Host Interface Reference Manual* gives a detailed description of the available commands, we will only present a brief example to demonstrate how to use the interface program.

WARNING

By design, the commands available through this program allow you to exceed typical robot speeds and to move the robot to unsafe positions. Always be prepared to stop the robots by breaking the light curtain or by pressing one of the *Emergency Stop* buttons.

Computer Control Example:

The intent of this example is to give you practice controlling the robotic arm's joint positions and velocities, and to see how the servo gain settings affect the motion of the robot. In thie example, you will command the robots to move each joint slowly a moderate distance, then move the robot to another position with a higher velocity. You will also learn how to move the robot's joints by issuing a velocity command.

It is assumed the Merlin has been initialized as described in Section 3.1, the light fence has been reset so that power is being applied to the motors, and the batch file *computer* has been initiated on the Compaq. Select the HSHI commands in the order listed below:

Step/Command

1. 1 - Set servo parameters. Enter a value of 1 for each parameter (maximum acceleration, maximum velocity, loop gain).
2. 5 - Command joint angles. Enter 15 degrees for each joint of the robot and observe the robot's motion.
3. 1 - Set servo parameters. Enter 16 for maximum acceleration, 8 for maximum velocity, and 3 for loop gain.
4. 5 - Command joint angles. Enter - (negative) 30 degrees for each joint. Observe the robot's motion.

CAUTION

The following command will cause each joint of the robot to move at the specified velocity. Be prepared to enter command 0 - STOP MOVING as soon as the robot moves a short distance.

5. 9 - New velocity. Enter a value of + 700 counts/second for each joint. As the robot begins its motion, enter command 0 - STOP MOVING.
6. 8 - New position. Enter a value of 0 for each angle. The robot will return to the calibration position.
7. 1 - Set servo parameters. Enter a value of 1 for each parameter.
8. 18 - Exit HSHI. Your example session is over. Press the *Push to Stop* button on the light fence control panel to engage the light fence.

CAUTJON

You should reset the three servo parameters to 1 before terminating each session. This will prevent inadvertent motion of the robot if another program is run.

It is helpful to return the robot to its calibration position (as we just did in step 6, above). This makes initializing the robot much easier the next time.

7 Analyzing Taskboard Data

There are three kinds of lies: lies, damned lies, and statistics - B Disraeli

You may use the followmg steps to analyze the data collected from the taskboard. Of course, any other method of data analysis might work just as well - the following paragraphs simply describe the methods currently being used.

When analyzing the data, you will be creating several files on the computer. The names of these files are significant. The following list explains the convention we have been using for naming the data files:

- *.raw - a file containing raw data from a taskboard experiment.

- *.avg - a file containing data from a taskboard experiment, averaged over indices of difficulty.

- *.sys - a file used by MYSTAT to perform descriptive statistics on the data. There are two types of *.sys files: *.sys and *sort.sys. The *sort.sys is a version of *.sys, sorted with respect to index of difficulty and peg tolerance (more on this later).

Next let's "walk through" a fictitious data analysis, assuming you are evaluating the data files *file1.raw*, *file2.raw*, and *file3.raw*. The procedures for evaluating a larger number of files is consistent with the steps described below.

7.1 DOS Commands

Assuming you're using the three data files listed above, you should first copy these files from the *nosc* subdirectory of the IBM PC to the *nosc* subdirectory of the Compaq (notice we are only concerned with the *.raw files, and we are not using the *.avg files - they contain low-pass filtered data that appears to increase the data's correlation). After changing directories to the *nosc* subdirectory on the Compaq, you should create a file containing all the raw data you're evaluating. You do this with the DOS command

```
copy file1.raw+file2.raw+file3.raw filtotal.raw
```

Notice we've named the output file *filtotal.raw,* although any unique fileuame will work. Be sure you give your filename a *.raw extension, though. The DOS concatenation command we've just performed extends to more than three files.

7.2 MYSTAT Commands

To use MYSTAT for descriptive statistics, you must perform a series of steps, as follows:

- Type *mystat* when you're in the *nosc* subdirectory of the Compaq computer. Tap *Enter* to see the main menu.
- Type *submit nosc.* This prepares MYSTAT to accept the *.raw file. Tap *Enter* when prompted.
- Tap the *Escape* key to move the cursor to the lower half of the screen. You will see the > prompt appear.
- Type *get.* When MYSTAT reports that UNIT 2 is missing, type in the name of your *.raw file. In this example, we would type in *filtotal.raw.* Wait until you see the data appear in columnar format on the screen.
- Since we want to continue naming our file *filtotal*, our next step is to type ***save filtotal.*** This causes MYSTAT to save the data in the file ***filtotal.sys***, which is a MYSTAT-compatible data file.
- After all the data has been written to *filtotal.sys*, type *quit* to return to the main menu. Because of a bug in MYSTAT, the screen will not clear properly. The next step will avert this problem.
- Issue the command ***use filtotal.*** This causes MYSTAT to input the data in the proper format. You will see a list of variable names on the screen. Tap *Enter* to return to the main menu.
- We can now perform some statistical analyses of the data. To view the Fitt's Law performance curve (in low resolution), type *plot mt*fittsid.* Tap any key to return to the main menu.
- To see the average movement time, plus the standard deviation, type ***stats mt.*** Tap *Enter* to return to the main menu.
- The most valuable data analysis has been to view the movement time statistics across the indices of difficulty. This process involves the following four steps:
  - Type ***save filsort.*** This will prepare MYSTAT to save our soon-to-be-sorted data in the file ***filsort.sys.***
  - Type ***sort distance, pt.*** This causes MYSTAT to sort the data according to distance moved and peg tolerance. These are the independent variables for determining the task index of difficulty. Tap *Enter* to return to the main menu.
  - Type ***use filsort*** to have MYSTAT read in the sorted data. Press any key to return to the main menu.
  - Type ***stats mt, fittsid /by distance, pt.*** This will display descriptive statistics for movement times across indices of difficulty.
- Type ***quit*** to exit MYSTAT.

MYSTAT contains many other analytical functions. You can learn more about these functions by typing ***help*** or ***help xxx***, where ***xxx*** is a particular MYSTAT function, than we can relate in this manual.

8 Error Recovery

Murphy was an optimist - Anonymous

This section should help you recover from unexpected errors. If these steps do not resolve the problem, you should consult the reference manual for the particular system causing the errors (see Section 9, *For Additional Information . . .*).

- Nothing happens when beginning telemanipulation. The most probable cause is that the MBA-Compaq communications are out of sync. First, disable the light fence. Then re-boot the Compaq and reset the MBA exoskeleton. Run *fitts* on the Compaq to restart exoskeletal control.

- The Merlin robots turn on, then immediately turn off. Check the *low air* buttonswitch on the Merlin control console. If this light is on, the building's compressors are probably at fault - check with SRL about the air supply.

- The light fence will not reset. Check that both reflector disks are attached to the wall of the lab, beside the MBA exoskeleton. Attach either disk that may have fallen. If both disks are attached and the light fence still will not reset, you must move the light fence transceiver post back and forth slowly until both green lights on the light fence control panel are lit. The light fence should now reset.

- One of the green light fence indicator lights will not light. If the problem is not with the reflector disks (see previous error condition), the light fence indicator bulb is probably burned out. Unscrew the plastic indicator covering (the actual green section itself), and replace the light bulb.

- The MBA LEDs turn off when resetting the joints, then several LEDs turn back on after each joint is initialized. The problem is with the electronics of the MBA backpack. Reset the exoskeleton, being careful to discharge any static from your body before touching the gripper light panels. Re-boot the Compaq, also, to ensure the communications are in sync. If the problem recurs, check with SRL about the backpack electronics.

- A particular LED will not turn off when the MBA exoskeleton is initialized. Make sure you have passed the appropriate joint through its entire range of motion (see Table 2, p. 11). If the light remains on, the problem is probably that the optical encoder's shaft has loosened from the link it is attached to. Have SRL reset the optical encoder shaft. Also, consult the *FITTS Technical Manual* to reset the kinematics of the exoskeleton to the new optical encoder setting.

9 For Additional Information . . .

To know that we know what we know, and that we do not know what we do not know, that is true knowledge - H D Thoreau

Consult the following references for detailed information about specific topics:

American Robot Corporation, *AR-BASIC (tm) Programming Guide,* Version 3.0. Pittsburgh, PA: June 1985.

American Robot Corporation, *High Speed Host Interface Reference Manual,* Issue 1. Pittsburgh, PA: August 1986.

American Robot Corporation, *MERLIN (tm) System Operator's Guide,* Version 3.0. Pittsburgh PA: June 1985.

Compaq Computer Corporation, *MS-DOS Version 4.0 Reference Guide.* April 1989.

Crabill, M., *et. al.,* "MBA Exoskeleton Technical Manual," *Unpublished AAMRL/SRL technical documentation.*

Fitts, P.M., "The Information Capacity of the Human Motor System in Controlling the Amplitude of a Movement," *Journal of Experimental Psychology,* 46: pp. 381-391: 1954.

Spain, H., *Peg-in-Hole Taskboard Documentation,* Version 1.0. NOSC-HI, Code 531: March 1989.

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